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VARIABILITY IN THE AUTOMATIC PROCESSING OF MEDICAL X-RAY FILM

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VARIABILITY IN THE AUTOMATIC PROCESSING OF MEDICAL X-RAY FILM

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June 1970

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Environmental Health Service
Bureau of Radiological Health
Rockville, Maryland 20852

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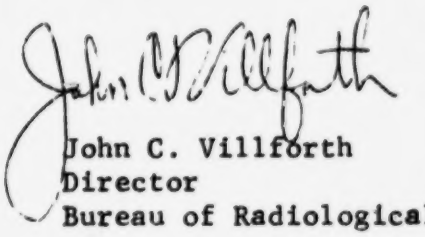

John C. Villforth
Director
Bureau of Radiological Health

PREFACE

There exist very little quantitative data concerning the amount of variation in the development of medical x-ray film in automatic processors. The purpose of this study was to establish a quantitative base from which questions involving the public health aspects of variability in automatic processing might be answered. Based on the results of this study, it is recommended that periodic monitoring of automatic processors be undertaken to help provide consistently good radiographs. This project was carried out in conjunction with the Radiological Health Division, D. C. Department of Public Health.

Robert L. Elder, Sc.D.
Acting Director
Division of Electronic Products

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ABSTRACT

Equally exposed films were developed in 26 automatic processors. Films were developed in 22 of these processors, one film per week for 3 consecutive weeks. The percent standard deviations of the film base-fogs, relative speeds, and average gradients were respectively 18, 12, and 4 percent. Films were developed in the other four processors on a daily basis for a one-month period. During this time, two of the processors required major servicing because of mechanical and chemical malfunctions. The percent standard deviations of the base-fog for the films developed in these two processors were 39 and 51 percent. For the other two processors, the percent standard deviations in the base-fog were both 11 percent.

VARIABILITY IN THE AUTOMATIC PROCESSING OF MEDICAL X-RAY FILM

1. INTRODUCTION

Automatic processing of medical x-ray film is becoming increasingly common. However, there exist very little quantitative data concerning the amount of variation in the development of film associated with automatic processing. The goal of this study was to establish a quantitative base from which questions involving the public health aspects of variability in automatic processing might be answered.

To establish this quantitative base, the study was divided into two sections. The purpose of the first section was to determine the amount of variation in film development, with regard to film base-fog, speed, and contrast, when equally exposed films were developed in different automatic processors. Twenty-two processors located in 12 hospitals in Washington, D. C., were used. These processors included only Kodak, Packoral, and Profexray models. The purpose of the second section of the study was to determine the amount of variation in film development with time for individual processors. Four automatic processors located at a 13th hospital in Washington, D. C., were used for this part of the study and were observed for a period of one month.

2. PROCEDURE

2.1 GENERAL

The following procedure was used for the study: 190 films were equally exposed, producing on each film two step tablets of nine densities each; 20 of these films were manually developed in the laboratory's sensitometric system to provide controls; three test films were developed in each of twenty-two processors to determine the overall variations in film development among automatic processors; a series of films was developed in four additional processors over a period of one month to determine the variation in film development with time for individual processors; the step tablet densities on each film were read with a densitometer for all the films that were developed; using the step tablet densities, a density-versus-relative exposure curve was plotted for each film, from which the base-fog, relative speed, and average gradient were obtained; and finally the three film parameters were statistically analyzed.

2.2 FILM EXPOSURE AND MONITORING

Two hundred Dupont Cronex IV, 8-inch by 10-inch Day Pack Films from the same emulsion batch were obtained for this study. This film brand was selected because the majority of the thirteen hospitals surveyed use it, because it has the capability of being either manually processed (necessary for the control films) or automatically processed, and because it can be processed in both rapid and regular speed processors.

After each film had been numerically labeled, the films were exposed to x rays in their day pack envelopes; that is, without screens. A sector wheel similar to the one described by Hurter and Driffield (1) was utilized. The sector wheel is a leaded, disc-shaped device with concentric slits of various lengths (figure 1). By rotating the sector wheel at a constant rate in front of a film that is being exposed, a step tablet of various densities is produced. The density of a given step depends on the length of its correponding concentric slit and the number of revolutions of the sector wheel, which together determine the duration of the exposure. The sector wheel was rotated at two revolutions per minute and had nine slits, the largest being 71 percent of the complete circle. A factor-of-two sector wheel, one that is designed so that two adjacent steps in the step tablet differ by a factor of two with regard to exposure, was used. Thus, each film received a binary time scale exposure, the smallest being 1/256 of the largest exposure. A sector wheel was used rather than a metallic step tablet so that each step in the tablet would be produced by a beam of the same quality.

Since the range of interest with respect to film density in medical diagnostic roentgenography is from approximately 0.25 to 2.0 density units above base-fog (2), and since each step in the film tablet differed from its adjacent step by the rather large exposure factor of two, two step tablets were produced on each film. The second tablet produced on each film received an exposure of two-thirds that of the first tablet. In this way at least six steps with densities in the region of interest were made available out of the total eighteen steps (figure 2).

The exposure delivered to each film was monitored with an ionization chamber-electrometer system. The purpose of monitoring was to limit the variability in the exposure delivered to the film by detecting and eliminating those films whose exposure values were significantly different from the mean exposure value. The percent standard deviation in the exposures of the films that were used in the study was less than

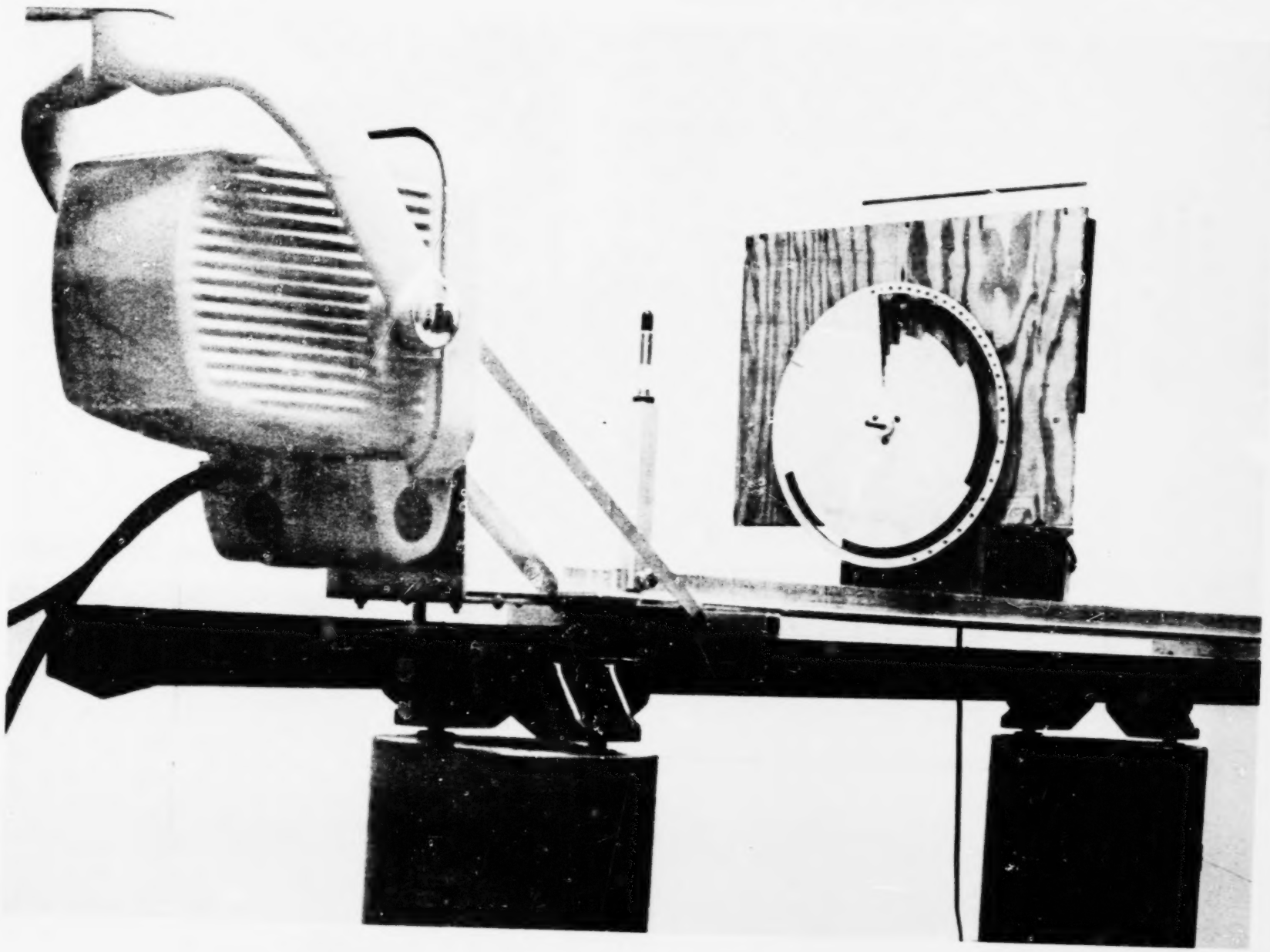


Figure 1. Factor-of-two sector wheel used in exposing films.

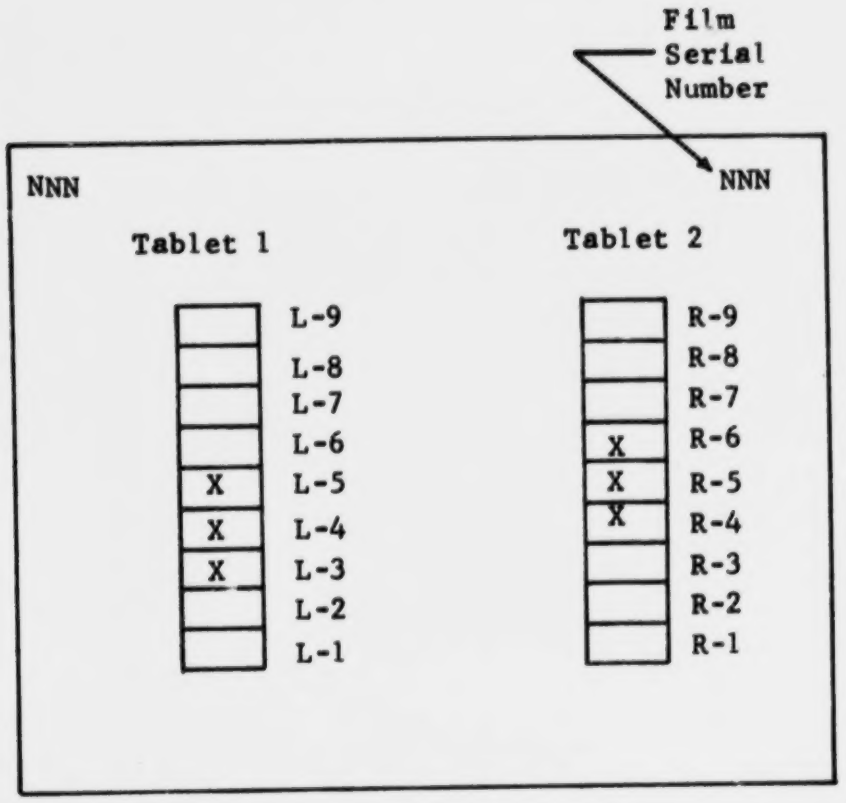


Figure 2. Density step tablets produced on a typical film, with a designation (X) of those steps used to obtain the density-versus-exposure curve.

one percent. No attempt was made to determine the roentgen exposure to the film since relative exposures were sufficient to plot the density-versus-exposure curves and to make intercomparisons. Each film was exposed with a General Electric "Maximar-100" operating at 60 kVp and 3 mA. The added filtration was 3.0 mm of aluminum, and the source-to-film distance was 24 inches. The exposure time for the first step tablet was 90 seconds, and for the second step tablet 60 seconds. After exposure, all the films were stored for a minimum of 4 days to ensure stabilization of the latent image.

2.3 FILM DEVELOPMENT

Variations in the film emulsion, the exposure technique, the reading of the densitometer, and the manipulation of the data were undesired sources of variability in film base-fog, relative speed, and average gradient. Therefore, twenty exposed films were selected for controls and developed in the XECL sensitometric facility. Base-fog, relative speed, and average gradient variations were obtained from these control films and used as baseline results with which the variations in these three film parameters of the automatically processed films could be compared.

The control films were developed for 5 minutes in Kodak Liquid X-ray Developer which was agitated every 15 seconds with 1-second nitrogen bursts. The temperature of the solution was 68°F. The films were then placed in a stop bath for approximately 30 minutes, and finally rinsed in Kodak Photoflow solution.

A total of 66 films was developed in 22 automatic processors located in 12 hospitals in Washington, D. C. (table 1). Three randomly selected films were developed in each of the first 22 processors listed, one film per week for three consecutive weeks. There was no attempt to schedule a time or date for a film to be processed in a given processor. The films were developed in the hospitals at various times between 10 AM and 4 PM on regular working days.

Films were also developed in four additional automatic processors located in the 13th hospital (table 2). Two films were developed in each processor, one in the morning and one in the afternoon, on the days indicated in table 2 over a 4-week period.

Table 1. The processor index number, facility index number, make and model, and processing times of the automatic processors.

Processor index number	Facility index number	Make and model	Approximate processing time
1	1	Kodak M-3	3 min
2	2	Kodak M-6N	90 sec
3	2	Kodak M-6N	90 sec
4	3	Kodak M-6N	90 sec
5	3	Profexray	90 sec
6	3	Kodak M-4	90 sec
7	4	Pako	4 min
8	5	Kodak M-4B	90 sec
9	5	Kodak M-4A	90 sec
10	5	Kodak M-4B	90 sec
11	6	Profexray	4 min
12	7	Pako	3 min
13	7	Kodak M-3	3 min
14	7	Pako	4 min
15	8	Pako	4 min
16	8	Pako	4 min
17	9	Kodak M-3	3 min
18	10	Kodak M-3	3 min
19	10	Kodak M-6N	2 min
20	11	Kodak M-5	5 min
21	12	Kodak M-4B	90 sec
22	12	Kodak M-4B	90 sec
23	13	Kodak M-3	4 min
24	13	Kodak M-3	4 min
25	13	Kodak M-6N	3 min
26	13	Kodak M-6N	6 min

Table 2. Days on which films were developed in the four processors used to determine variations in film development with time.

	Monday	Tuesday	Wednesday	Thursday	Friday
1st Week	X	X	X	X	X
2nd Week	X			X	X
3rd Week		X		X	
4th Week	X		X		X

2.4 DENSITOMETER READINGS

After all the films were developed, the base-fog densities and the densities of the step tablets were read with a Macbeth Model 12A densitometer. Not all the steps of the tablets were read because the densities of some steps were not in the region of interest (0.25-2.00). Those that were read for each film are indicated by x's in figure 2. After the densitometer had been warmed up for a period of an hour, one person read the densities. The densitometer was recalibrated periodically, approximately every five films, at a density of 1.04 with an Ansco Quanta Log Step tablet. The meter of the densitometer could be read to an accuracy of $\pm$ 0.02 density units.

2.5 DETERMINATION OF BASE-FOG, RELATIVE SPEED AND AVERAGE GRADIENT

The three film parameters used to measure variation in film development were base-fog density, relative speed, and average gradient, as defined below.

The base-fog density is the density of an unexposed portion of a developed film due to translucency of film base and emulsion fog. One effect of high base-fog is to reduce the contrast of the radiograph; the higher the base-fog, the more the contrast is reduced. The average base-fog density was obtained from three densitometer readings of each film at various positions. Base-fog is measured in density units (du).

Film speed is a quantity which describes the sensitivity of the film to radiation, and is defined by the American Standards Association (3) (now referred to as the American National Standards Institute) as the reciprocal of the exposure in roentgens required to produce a density 1.0 above the base-fog density under strictly defined exposure and development conditions. The greater the speed of a film, that is the more sensitive it is, the lesser is the exposure required to produce a given density above base-fog.

Relative speed, defined here as the reciprocal of the number of relative exposure units required to produce a density of 1.0 above base-fog, was used since the true exposure in roentgens was not measured, nor was it needed to fulfill the purpose of the study. Relative speed is measured in inverse relative exposure units $(reu)^{-1}$.

The relative film speed was obtained by plotting a density versus relative exposure (D-E) curve for each film. The densities on the step tablet were read with a densitometer as discussed in the previous section. Since a factor-of-two sector wheel was used during the exposures, the exposure associated with a given step of a tablet differed

by a factor of two from its adjacent step. The exposure delivered to step "L-3" was arbitrarily defined as 1.5 relative exposure units. Consequently, the exposures associated with steps "L-4", "L-5", "R-4", "R-5", and "R-6" become, respectively, 3.0, 6.0, 2.0, 4.0, and 8.0 relative exposure units. A plot of a D-E curve for a typical film is shown in figure 3. The relative film speeds were determined from the D-E curve as indicated.

Film contrast refers to the slope of the characteristic curve of the film (i.e., density versus log relative exposure). Film contrast depends on the type of film, the processing it receives, and the density. Radiographic contrast, which is a function of film contrast and subject contrast, enables one area to be distinguished from another when viewing a finished radiograph. The average gradient was the quantity used to measure film contrast. The average gradient as defined by the American Standards Association (3) is:

$$\text{Average gradient} = 1.75/(\text{Log}_{10}E_2 - \text{Log}_{10}E_1)$$

where E_2 = exposure at density 2.0 above base-fog

and E_1 = exposure at density 0.25 above base-fog.

In this study the average gradient was slightly redefined because film densities equal to or greater than 2.0 above base-fog were not read from the step tablets. The average gradient was redefined as:

$$\text{Average gradient} = 1.00/(\text{Log}_{10}E_2 - \text{Log}_{10}E_1)$$

where E_2 = exposure at density 1.10 above base-fog

and E_1 = exposure at density 0.10 above base-fog.

The average gradient for each film was determined by reading the E_2 and E_1 values from the D-E curve and making the above calculation. The average gradient is measured in density units per log exposure unit (du/leu).

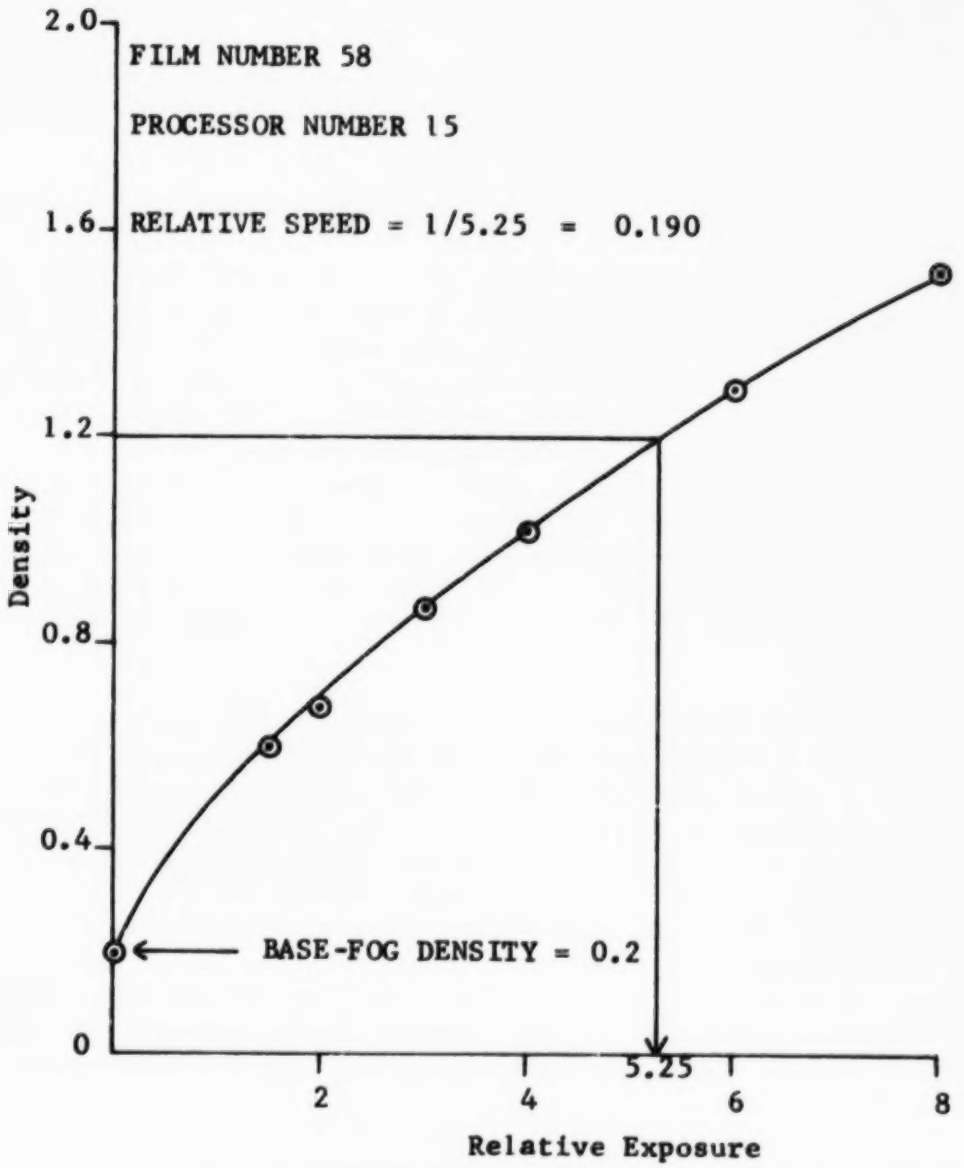


Figure 3. Typical density-versus-exposure curve of a film showing the method by which the relative speed was determined

3. RESULTS

The results are divided into two sections. In the first section the variations in base-fog density, speed, and average gradient are presented for the test films developed in 22 automatic processors and for the control films. In the second section the time variations in these parameters are presented for films developed in four additional processors.

3.1 VARIATION IN FILM DEVELOPMENT AMONG 22 AUTOMATIC PROCESSORS

The base-fog densities of each of the 66 films developed in the 22 automatic processors are shown in figure 4. The data are arranged chronologically so that for a given processor the densities of the films developed in the first, second, and third weeks are correspondingly placed to the left, center, and right on the chart. The mean and the standard deviation of the base-fog density distribution were computed to be 0.182 and 0.033, respectively. The range was from 0.14 to 0.27 density unit. In figure 5, the base-fog density distributions of the 66 automatically processed films and of the 20 control films are presented. The mean base-fog density of the control films was also 0.182. The standard deviation of the distribution was 0.008.

From figure 6 it is possible to determine the probability that any two control films or any two automatically processed films differ by less than a given percent with regard to base-fog density. These curves were obtained by first computing the absolute value of the percent differences in base-fog density for all pair combinations of the 20 control films, and for all pair combinations of the 66 automatically processed films. Then the cumulative percent distributions of these percent differences were plotted. It can be seen that there is a probability of 0.5 that the base-fog densities of any two control films are within 2 percent of each other, while for any two automatically processed films the corresponding percent difference increases to 15 percent.

For each of the three graphs just presented for the base-fog, there are corresponding graphs for the other two film parameters, relative speed and average gradient. These graphs are shown in figures 7 through 12. Some of the data from figures 4 through 12 are summarized in table 3.

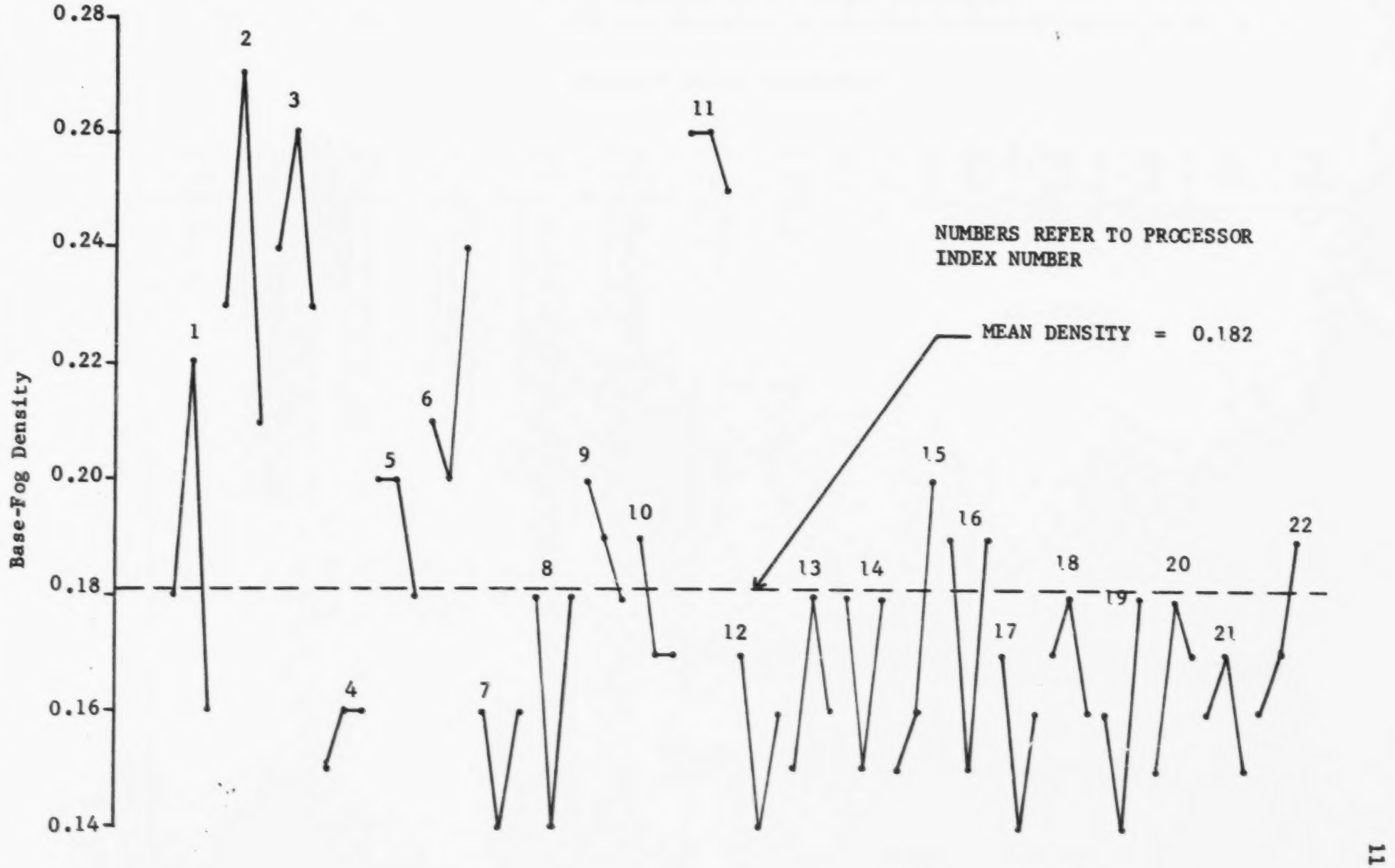
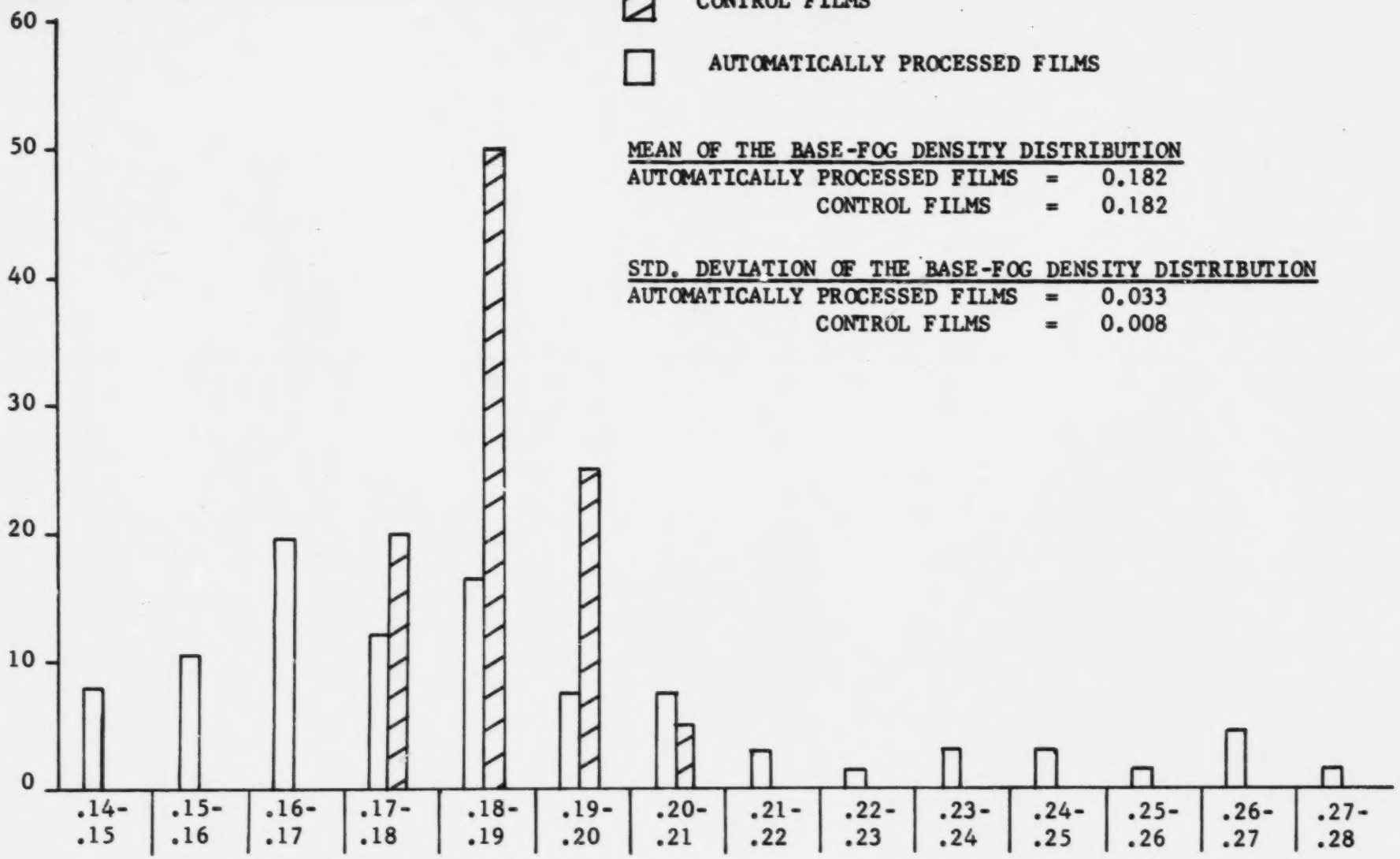


Figure 4. The base-fog densities of 66 films developed in 22 automatic processors in three consecutive weeks.



MEAN OF THE BASE-FOG DENSITY DISTRIBUTION

AUTOMATICALLY PROCESSED FILMS	=	0.182
CONTROL FILMS	=	0.182

STD. DEVIATION OF THE BASE-FOG DENSITY DISTRIBUTION

AUTOMATICALLY PROCESSED FILMS	=	0.033
CONTROL FILMS	=	0.008

Figure 5. Distributions of the base-fog densities of the hand-processed control films and of films developed in automatic processors.

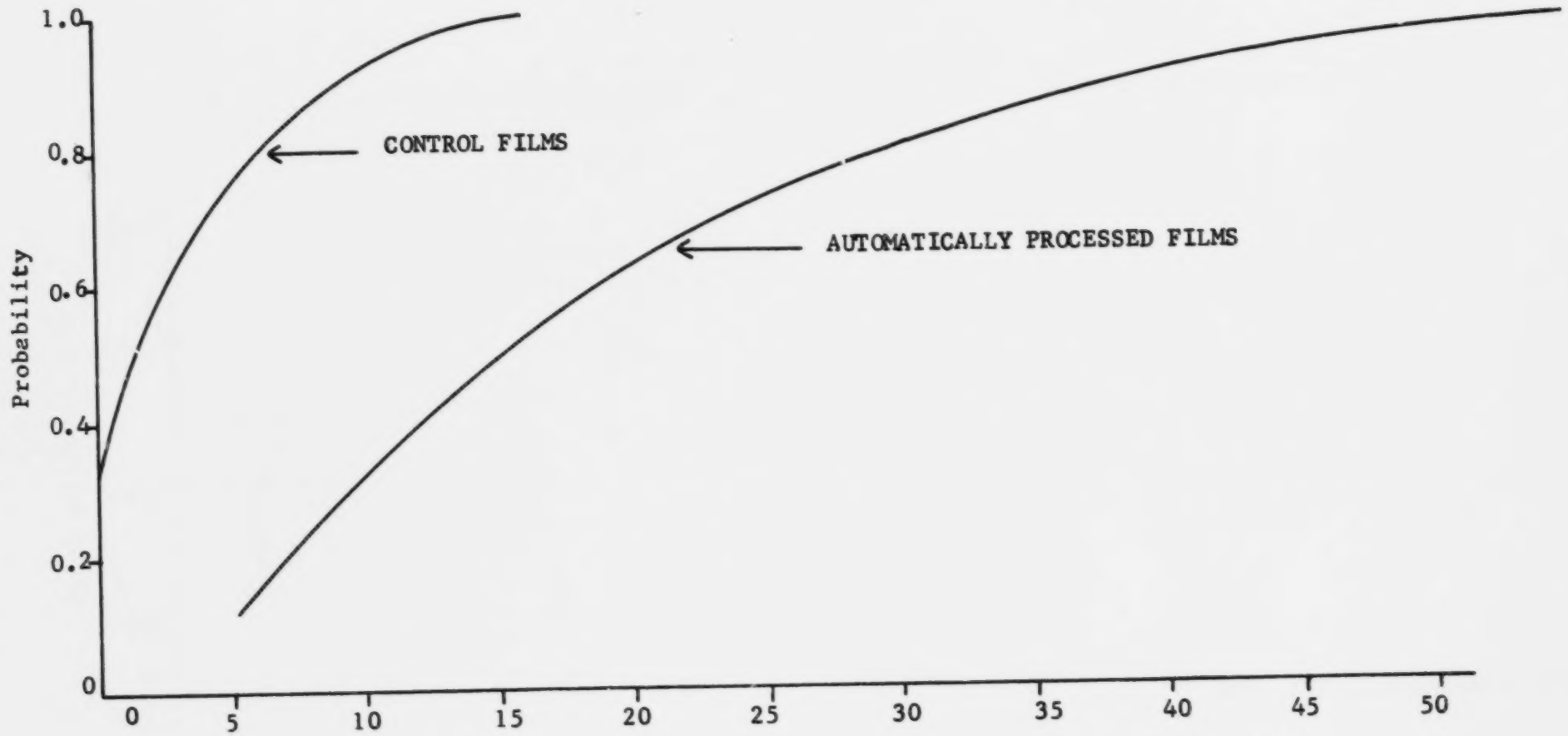


Figure 6. Probability of randomly selected film pairs having less than a given percent difference in base-fog density.

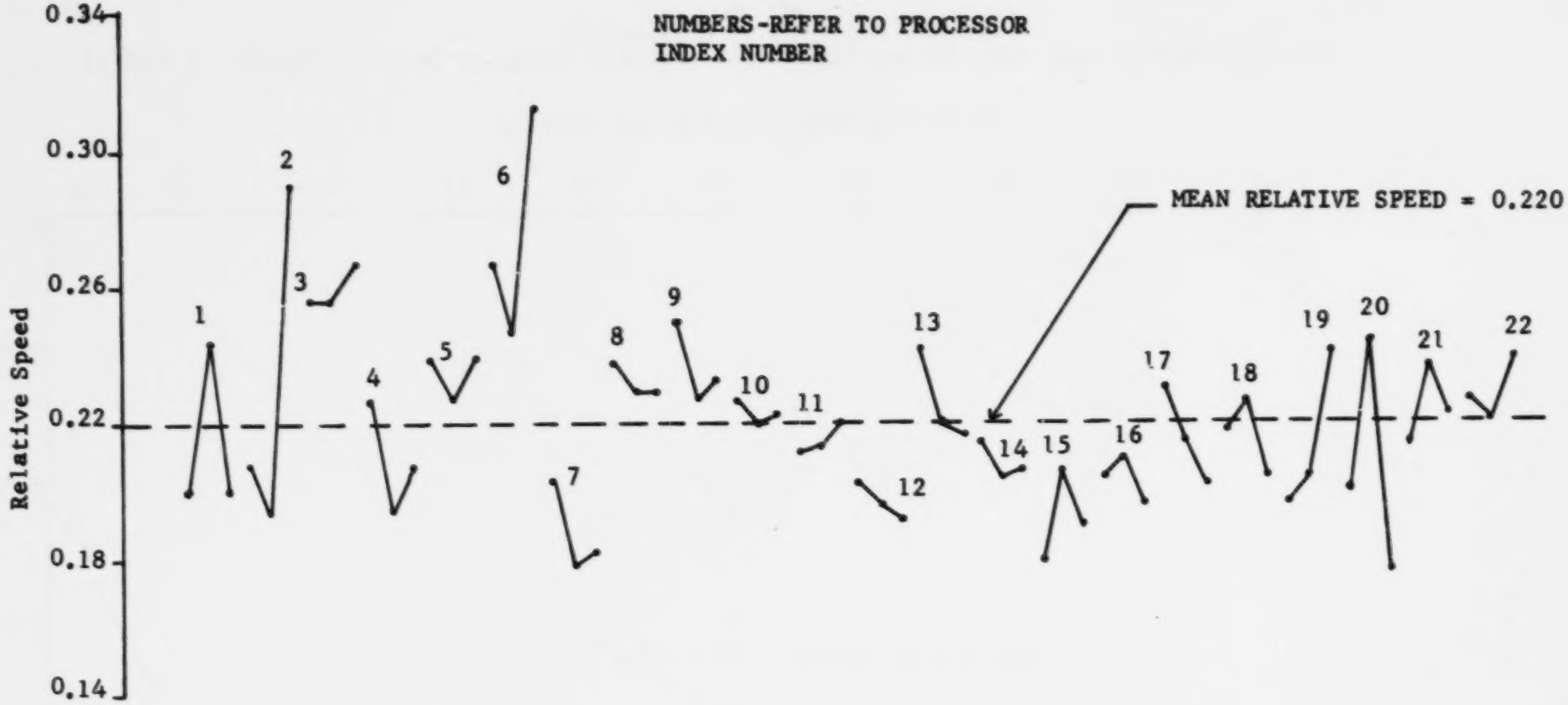


Figure 7. The relative speeds of 66 films developed in 22 automatic processors in three consecutive weeks.

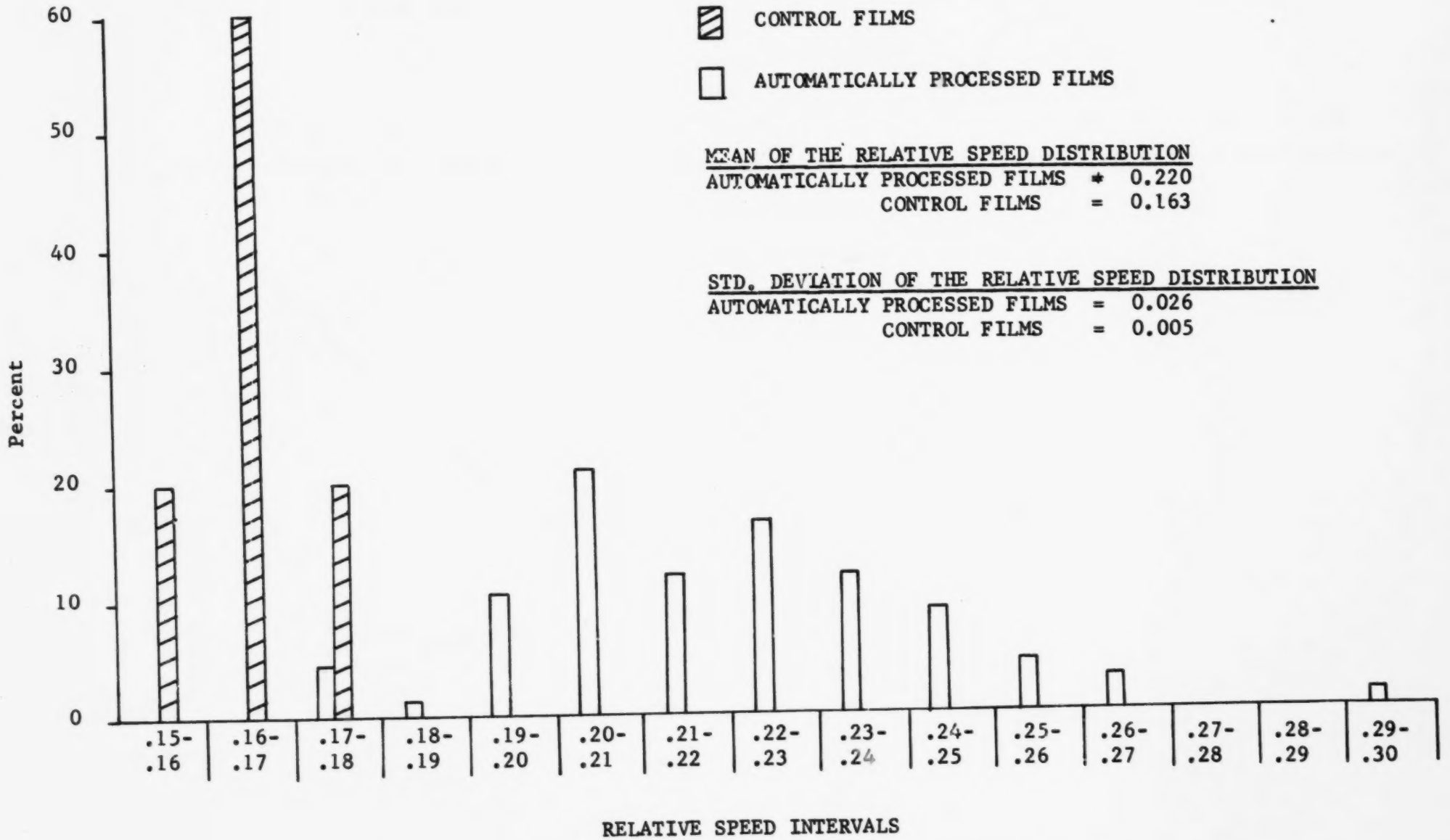


Figure 8. Distributions of the relative speeds of the hand-processed control films and of the films developed in automatic processors.

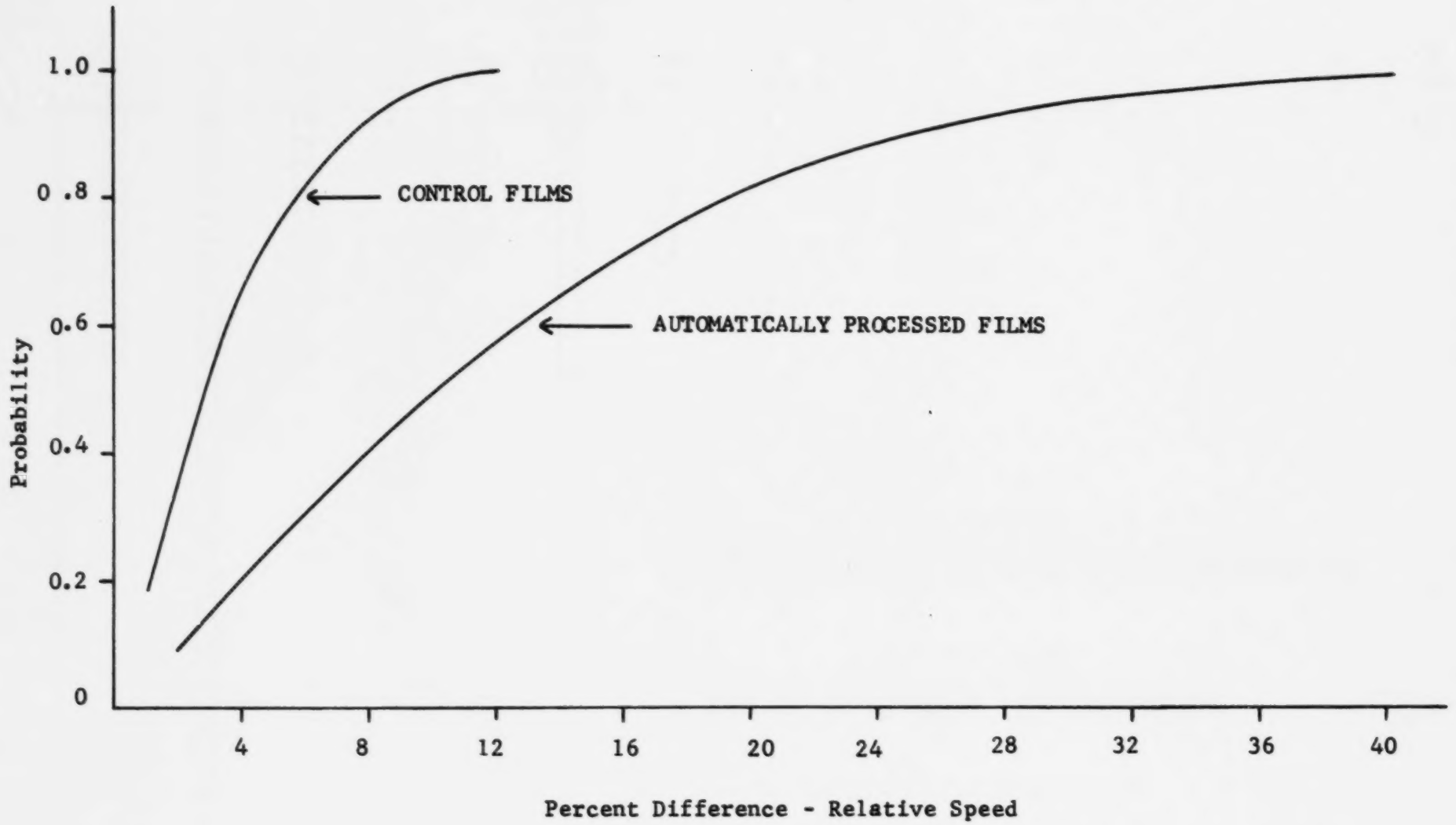


Figure 9. Probability of randomly selected film pairs having less than a given percent difference in relative speed.

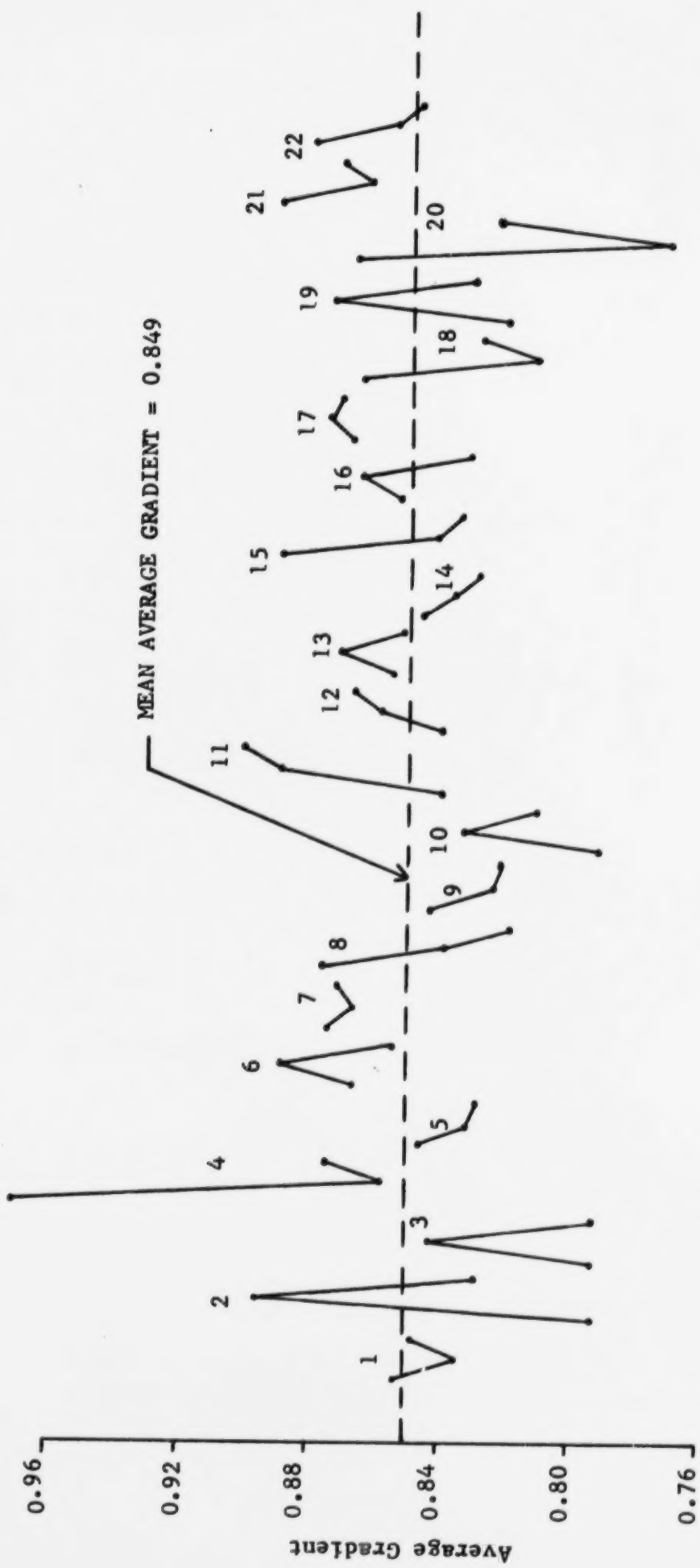


Figure 10. The average gradients of 66 films developed in 22 automatic processors in three consecutive weeks.

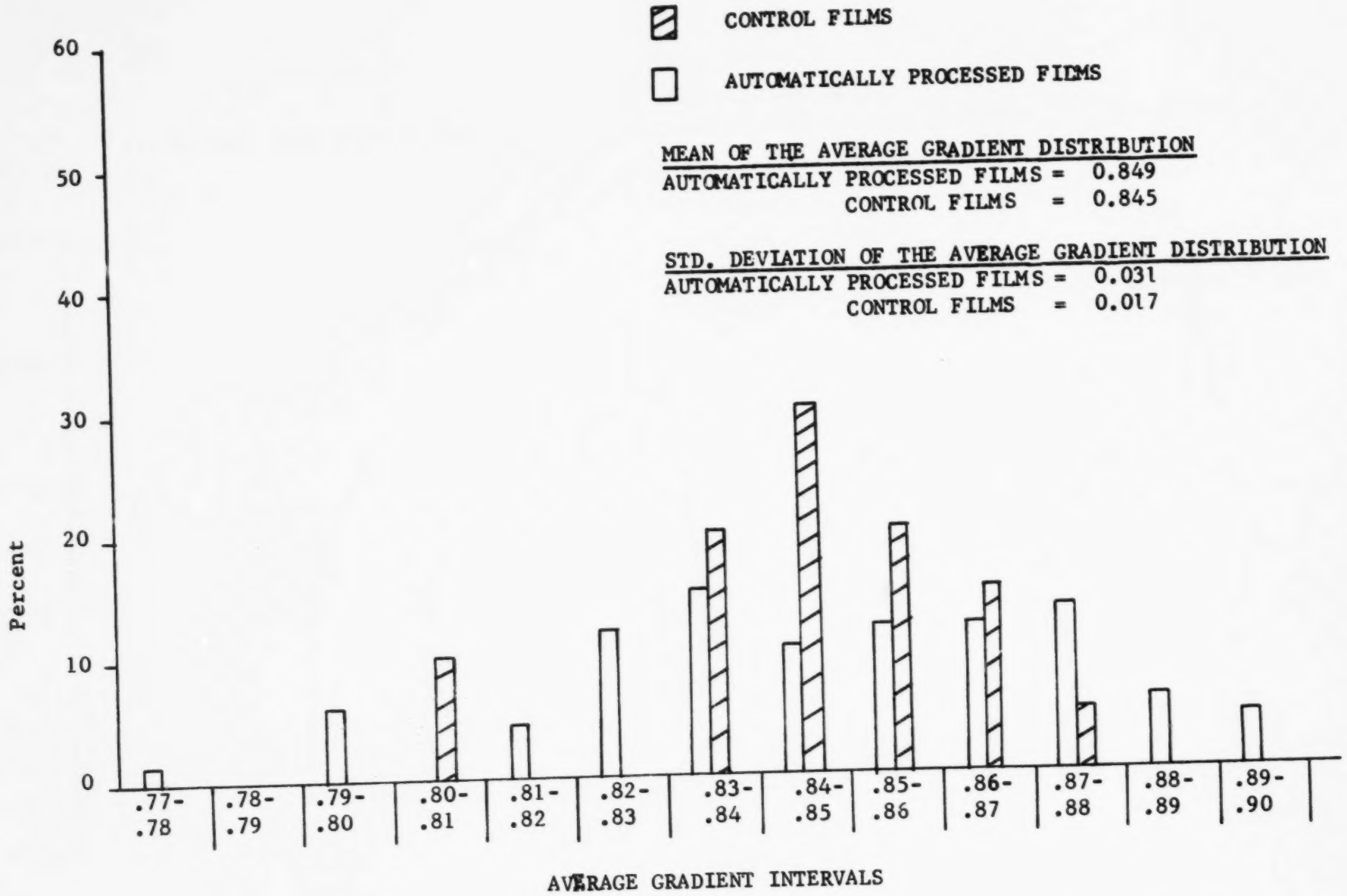


Figure 11. Distributions of the average gradients of the hand-processed control films and of the films developed in automatic processors.

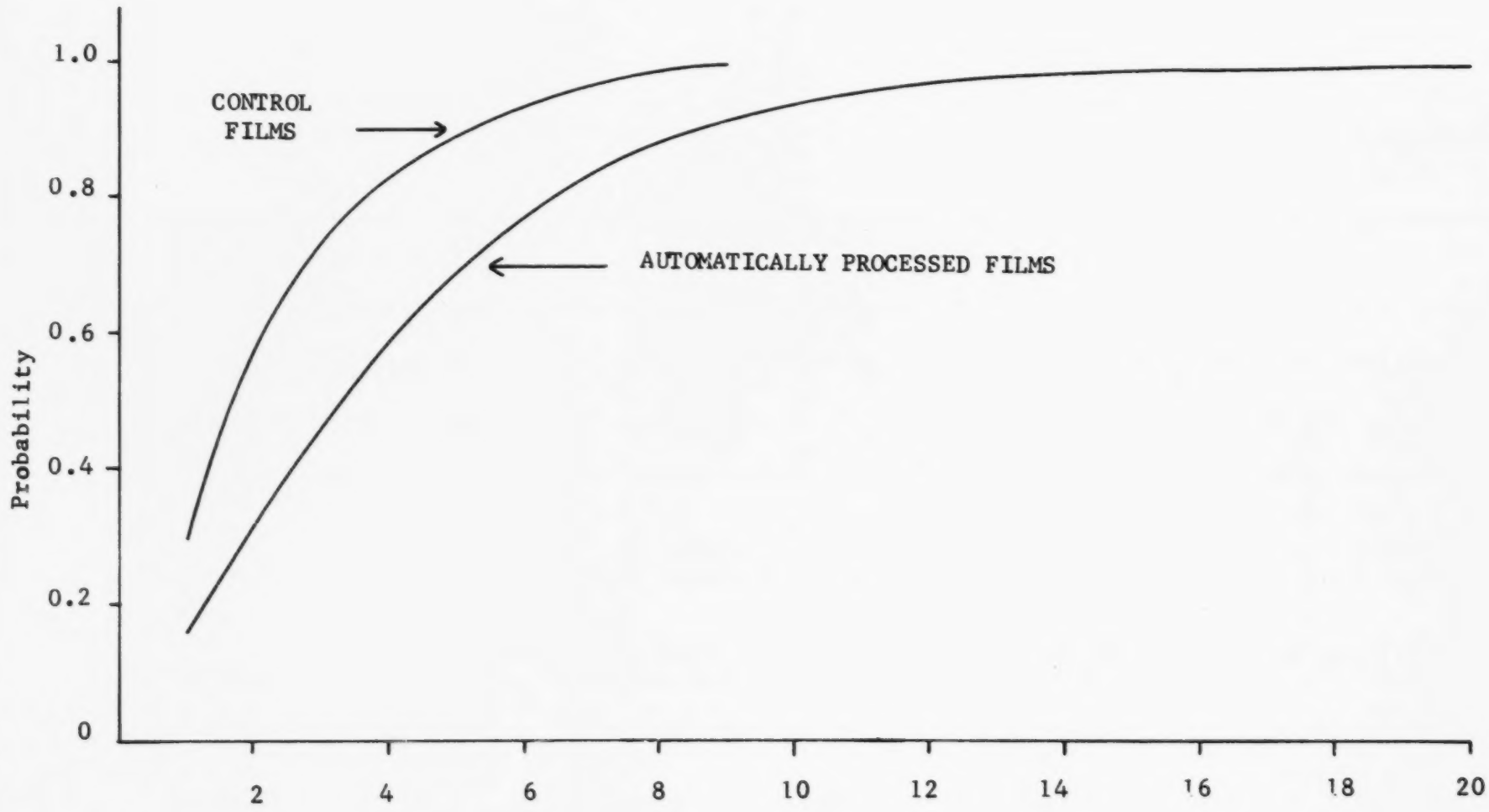


Figure 12. Probability of randomly selected film pairs having less than a given percent difference in average gradient.

Table 3. Summary of data from figures 4 through 12.

	20 Control Films			66 Automatically Processed Films		
	Base-fog	Relative Speed	Average Gradient	Base-fog	Relative Speed	Average Gradient
Mean	0.182	0.163	0.845	0.182	0.220	0.849
Standard Deviation	0.008	0.005	0.017	0.033	0.026	0.032
Percent Standard Deviation	4	3	2	18	12	4
Median Percent Difference Between Film Pairs	1	3	2	15	10	3
Range	0.17-0.20	0.15-0.17	0.80-0.87	0.14-0.27	0.18-0.31	0.77-0.97

As can be seen in table 3, the percent standard deviation, median percent difference, and range were less for the control films than for the automatically processed films. This shows that the variations observed in the automatically processed films cannot merely be attributed to errors or variation in the film emulsions, exposure technique, densitometer readings, and data manipulation.

The base-fog was the most variable of the three film parameters, having an 18 percent standard deviation for the automatically processed films, while the relative speed and average gradient, respectively, had a 12 and 4 percent standard deviation.

It is interesting to note that the speed of the automatically processed films averaged 35 percent greater than the speed of the manually developed films. The two distributions are shown in figure 8. Unpublished data of Bates (4) also indicate that some brands of film are developed to higher densities, and therefore higher speeds, when they are hand developed at elevated temperatures with chemicals normally used in automatic processors than when they are hand developed normally; i.e., according to manufacturer's specifications. However, his data also indicate that development in this manner reduces the contrast factor compared to normal development. Our data do not show a significant reduction in average gradient (figure 11).

3.2 DAILY VARIATION IN FILM DEVELOPMENT FOR FOUR AUTOMATIC PROCESSORS

The daily variation in base-fog, relative speed, and average gradient for films developed in processors number 23, 24, 25 and 26 are presented, respectively, in figures 13, 14, 15 and 16. In figure 13 it can be seen that during the first week processor number 23 developed films with base-fogs of approximately 0.21 density units (du), relative speeds of approximately 0.22 inverse relative exposure units $(reu)^{-1}$ and average gradients of approximately 0.86 density units per log exposure unit (du/leu). However, during the second week the base-fog gradually increased to as high as 0.48 (du). The relative speed and average gradient dropped to 0.17 $(reu)^{-1}$ and 0.79 (du/leu), respectively. On the sixteenth day a broken drive belt on the dryer was replaced and the unit was thoroughly cleaned, including the rollers and tanks. As a result of these changes the base-fog, relative speed, and avarage gradient of the films processed during the third week were very much improved. The base-fog decreased to approximately 0.16 (du), while the relative speed increased to about 0.22 $(reu)^{-1}$. The average gradient increased somewhat to about 0.83 (du/leu). Near the end of the fourth week, the base-fog increased to 0.27 density units, and the relative speed and average gradient both declined. However, there were

not enough data to determine if these effects in the fourth week were due to normal fluctuations in the machine, or if the effects were caused by poor adjustment. The poor adjustment might have been caused by the replacement on the twenty-third day of all the rollers, gears, belts, tanks, and plumbing.

In figure 14, it is seen that during the first week and the beginning of the second week processor number 24 developed films with very high base-fog densities (approximately 0.44 du), low relative speeds (approximately 0.18 reu^{-1}), and low average gradients (approximately 0.78 du/leu). Two films had base-fogs as high as 0.52 density units. However, on the ninth day the unit was serviced, and the chemicals were completely changed to a new brand. A marked improvement was observed in all the film parameters when test films were subsequently processed. The base-fog decreased to 0.14 (du), the relative speed increased to 0.20 $(reu)^{-1}$, and the average gradient increased to approximately 0.90 (du/leu). During the following two weeks, the base-fog remained at about 0.16 (du), the relative speed fluctuated between 0.17 and 0.19 $(reu)^{-1}$, and the average gradient varied between 0.85 and 0.90 (du/leu).

Processors number 25 and 26 showed no gross variations in the film factors during the month.

The data from figures 13 through 16 are summarized in table 4. The means and percent standard deviations of each of the three film parameters are presented for the four sets of film developed in the four processors. For processors 23 and 24 the means and percent standard deviations are included for the group of films that was developed when the processors were operating normally; that is, without mechanical or chemical malfunctions, and also for the group of films that was developed when the processors were developing poorly, as well as for the films developed during the entire month. The means and percent standard deviations for the 20 control films and for the 66 films that were developed in the 22 automatic processors are also included for comparison purposes.

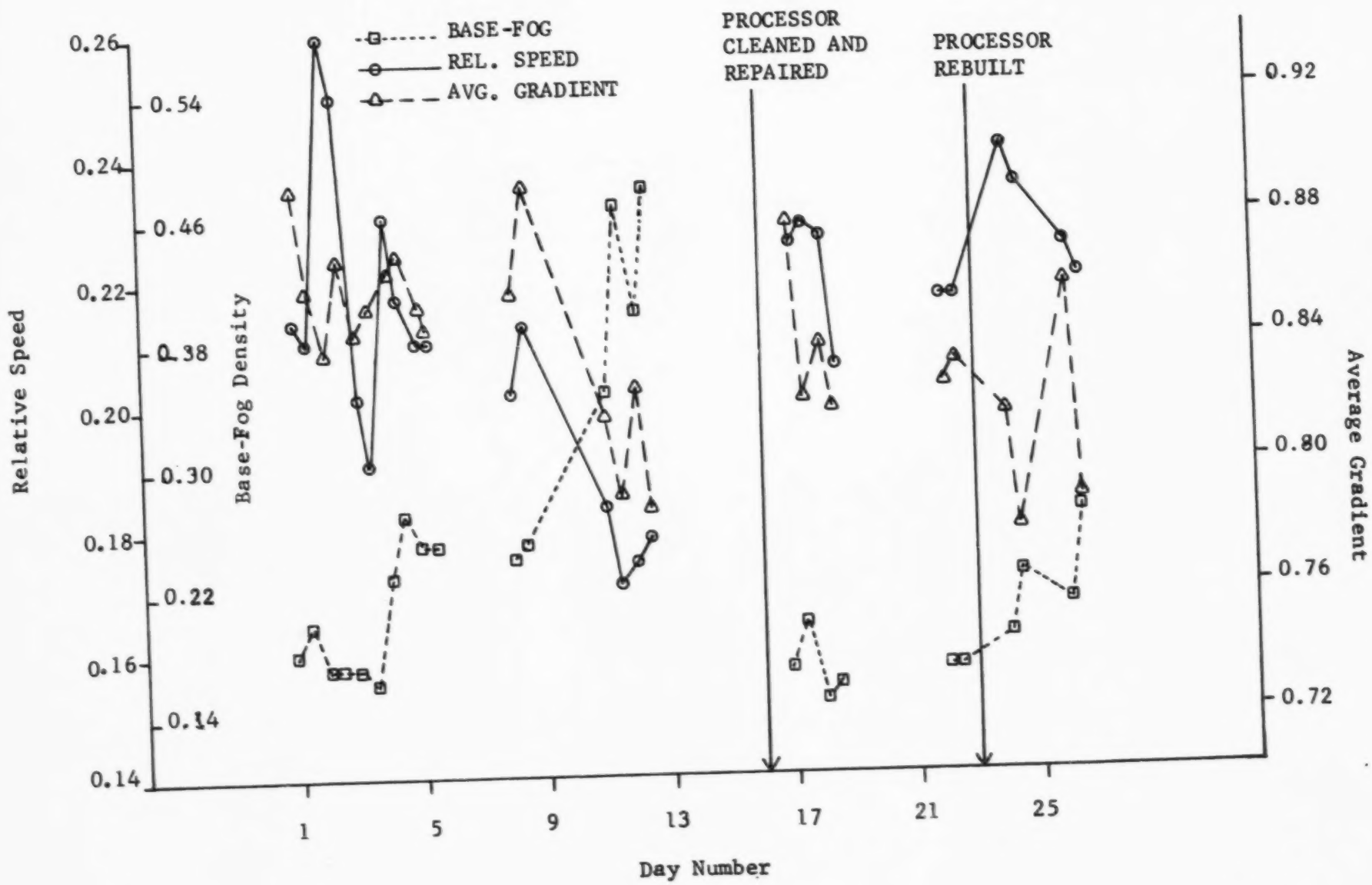


Figure 13. Daily variations of base-fog, relative speed, and average gradient for films developed in processor number 23.

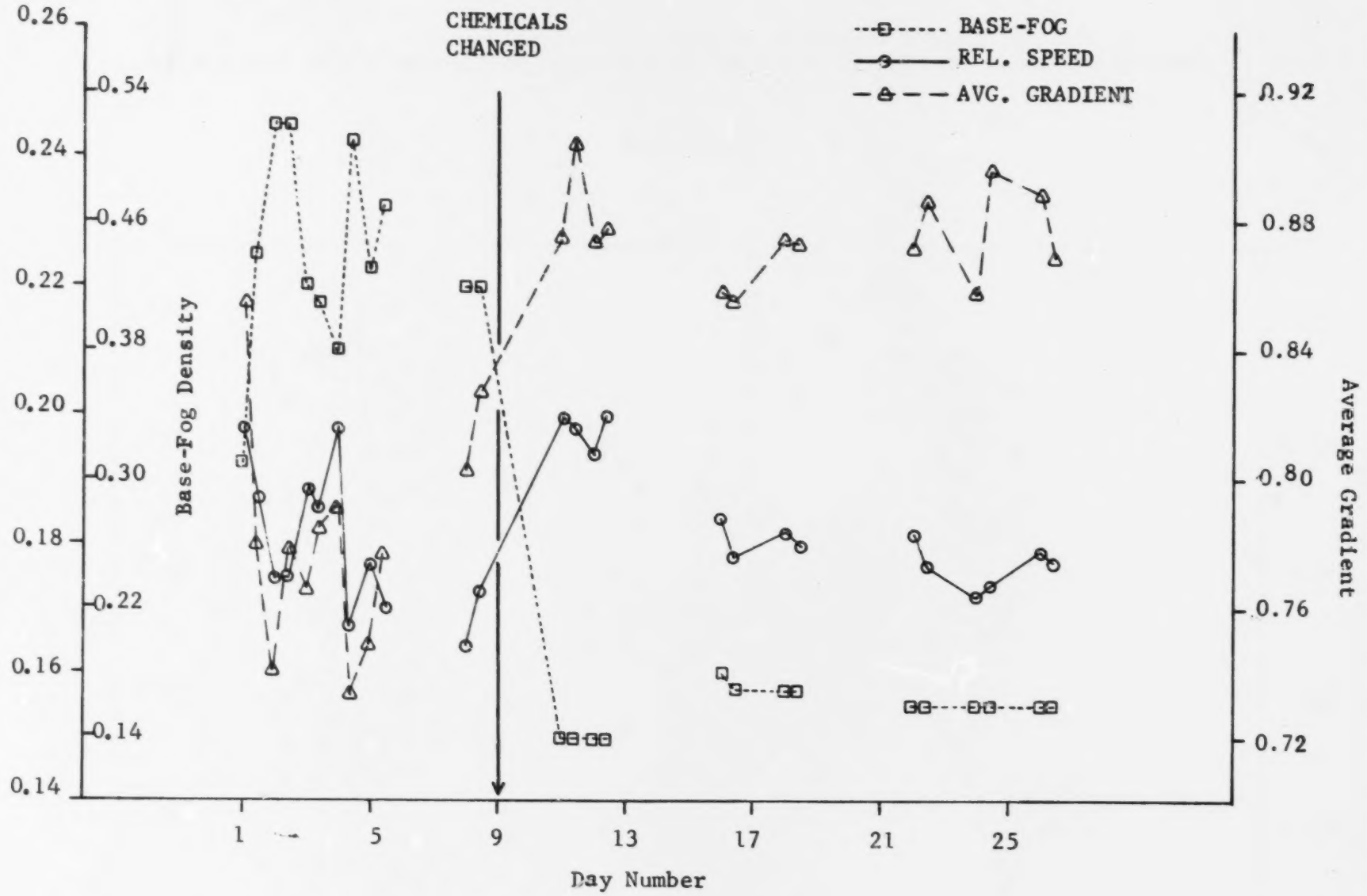


Figure 14. Daily variations of base-fog, relative speed, and average gradient for films developed in processor number 24.

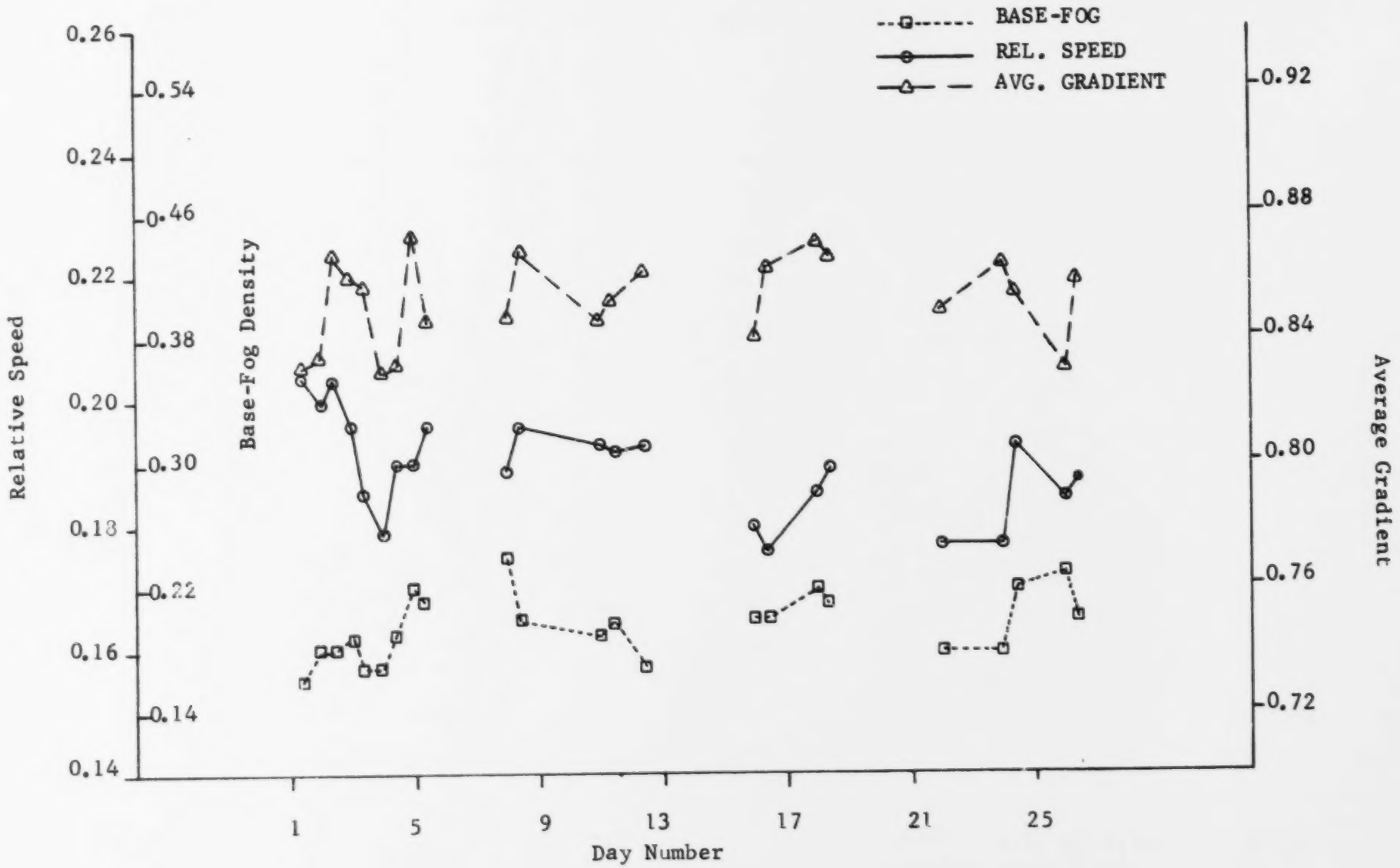


Figure 15. Daily variations of base-fog, relative speed, and average gradient for films developed in processor 25.

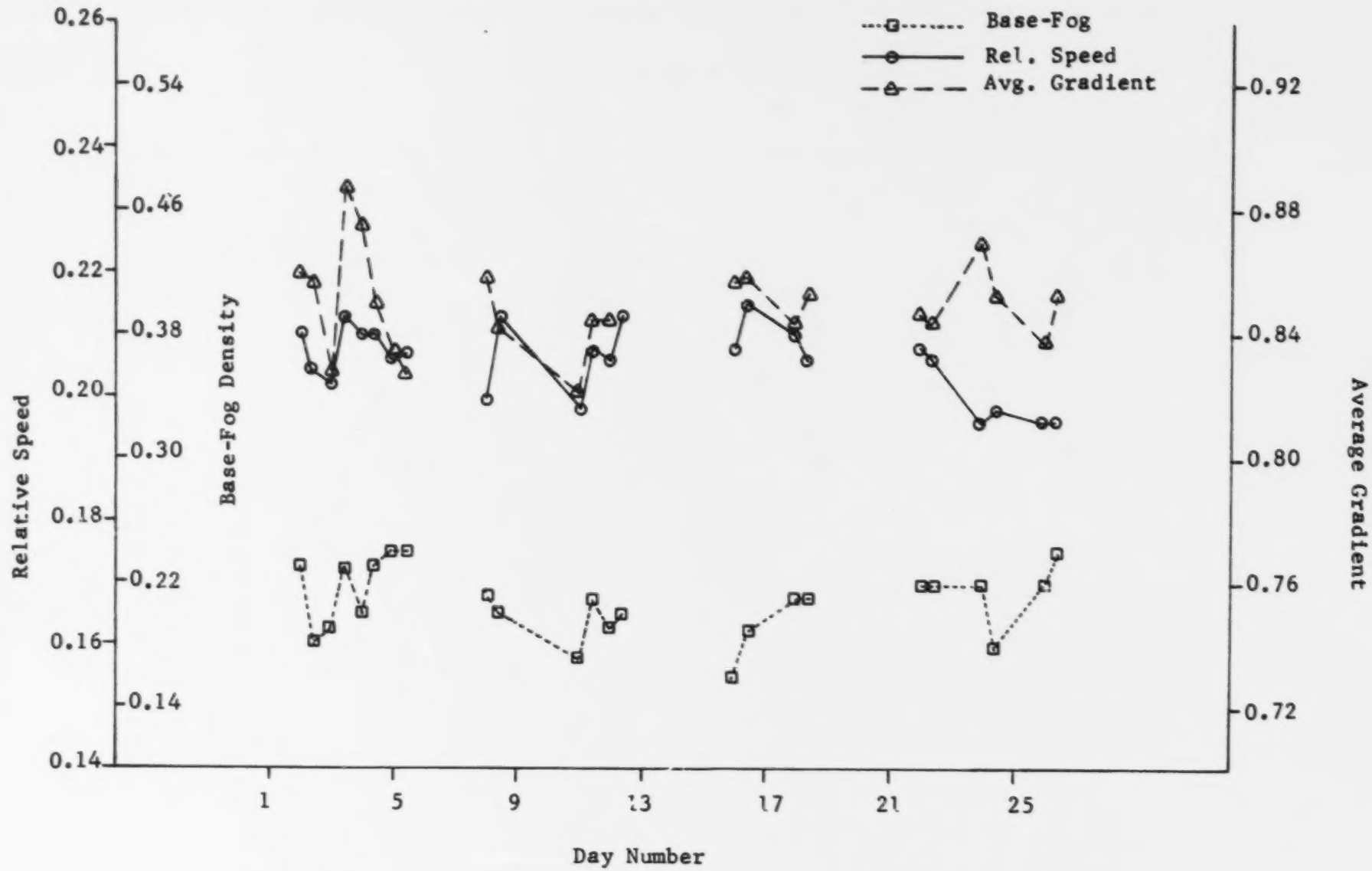


Figure 16. Daily variations of base-fog, relative speed, and average gradient for films developed in processor number 26.

Table 4. Means and percent standard deviations of base-fog, relative speed, and average gradient.

	Base-fog		Relative speed		Average gradient	
	Mean (du)	Percent standard deviation	Mean $(reu)^{-1}$	Percent standard deviation	Mean (du/leu)	Percent standard deviation
Control films (20)[a]	0.182	4	0.163	3	0.845	2
Processed films (66)	0.182	18	0.220	12	0.849	4
Processor #23						
All films (26)	0.237	39	0.214	10	0.838	4
Normal processing (22)	0.203	19	0.220	7	0.845	3
Poor processing (4)	0.425	14	0.177	3	0.805	2
Processor #24						
All films (26)	0.286	51	0.182	6	0.833	6
Normal processing (14)	0.158	8	0.184	5	0.876	2
Poor processing (12)	0.434	14	0.180	6	0.782	4
Processor #25 (23)	0.196	11	0.189	4	0.852	2
Processor #26 (24)	0.208	11	0.206	3	0.849	2

[a]Numbers in parenthesis are the number of films

4. SUMMARY OF RESULTS

The percent standard deviations of the base-fog, relative speed, and average gradient were respectively, 18, 12, and 4 percent for the 66 films developed in the 22 different processors. The corresponding values for the control films were 4, 3, and 2 percent. In terms of percent difference between film pairs it was found that there was a 0.5 probability of any two automatically processed films being within 15 percent of each other for base-fog, 10 percent for relative speed, and 3 percent for average gradient. There was a 0.5 probability of any two control films being within 1 percent of each other for base-fog, 3 percent for relative speed, and 2 percent for the average gradient.

Two distinct degrees of variation were observed in the month-long study of the four processors. Processors 23 and 24 showed gross variation in the film parameters, especially base-fog. The percent standard deviation of the base-fog for the films developed in these two processors were respectively 39 and 51 percent compared to a 4 percent standard deviation for the control films. These gross variations were probably due to a mechanical malfunction of the transport system and possibly due to contaminated or depleted chemicals. On the other hand processors 25 and 26, although showing no gross variations during the month, did exhibit some day-to-day variations. For the base-fog the percent standard deviations were both about 11 percent. The other two film parameters showed only slight day-to-day variation. The percent standard deviations of the relative speed were 4 and 3 percent for the films developed in the two automatic processors as compared with 3 percent for the control films. The percent standard deviations of the average gradient for the films developed in these two machines were both about 2 percent, the same as the percent standard deviation of the control films.

5. DISCUSSION

The sensitometric variations in automatic processing have been observed and recorded. However, two questions remain to be discussed. First, what are the causes of the variations, and second, how significant are the variations?

The fact that the 22 automatic processors included three different makes and several models, used different chemicals, and were serviced and maintained differently helps explain the variations in processing observed among them. However, "active" parameters, those that may undergo variations with time, such as water temperature, developer temperature, dryer temperature, and age of chemicals, were also probable sources of variability in processing. Changes in these active parameters were probably responsible for the normal time variations observed in the study of the four additional processors. Since no effort was made to establish a relationship between the variations observed and the multitude of parameters, no definitive statement with regard to the causes of the variations can be made. However, abnormal variations in film processing in two of the individual units were certainly caused by mechanical and chemical malfunctions.

The second question, how significant or important are the variations, is much more difficult to answer. The answer depends in part on the point of view of the person asking the question. The interpretation of the specific results presented in this study are purposely left to the individual reader who is confronted with a particular problem.

The goal of this study, as was mentioned in the introduction, was to establish a quantitative base from which questions involving the public health aspects of variability in automatic processing might be answered. Some situations where data from this report might be applied are discussed below.

To supervisors and administrators of radiographic departments, the question might arise, does automatic processing ensure an adequate processing facility, disregarding the occasional mechanical and chemical malfunctions of the units? To answer this question, some measure of adequate processing must be defined. According to Ter-Pogossion (5), "Fresh unexposed processed X-ray film may exhibit a low base-plus-fog density of about 0.12, but this value increases with time. A base-plus-fog density in excess of 0.20 is considered objectionable." The data from this study show that 12 of the 66 films (18 percent) developed in the 22 processors had base-fogs exceeding 0.20 density units. It can be seen that automatic processing in a clinical environment does not in itself ensure adequate processing.

To the individual radiologist at a facility where two or more processors are used, the question might arise, can the variability in automatic processing be significant enough to interfere with clinical judgement? Poznanski and Smith (6) have recognized the desirability of keeping variations between processors to a minimum. "Film density control is of major concern when two or more automatic processors are used in a radiologic department. This problem is more acute if the units are operated at different speeds or are of different designs." Whether or not variability in automatic processing would be of concern to a radiologist depends on the particular individual involved. However, from this study it is possible to obtain some idea of the magnitude of the variations involved. For example, from figure 6 it can be seen that there is 0.25 probability that randomly selected film pairs of the 66 films developed in the 22 processors will have a greater than 25 percent difference in base-fog density.

The radiologists or radiologic technologists at a facility where only one processor is located might be concerned with the significance of the day-to-day variations in an individual unit and ask how much day-to-day variation can be expected in automatic processors. Since only four automatic processors were studied for a period of one month, the answer to the above question can not be conclusive. However, it can be said that the base-fog densities of the films developed in the four processors, when they were functioning normally, ranged on the average from 0.15 to 0.23 density unit during the month. The corresponding averages of the 22 processors were 0.17 to 0.20 density unit.

Two of the four processors studied for the one-month period developed films to base-fog densities as high as 0.48 and 0.52 density unit. In the first processor the high base-fog density was probably due to a malfunction of the transport system. After the unit was cleaned and repaired, the base-fog dropped from 0.48 to 0.17 density unit. In the other processor the base-fog dropped from 0.52 to 0.14 density unit when the unit was serviced and the chemicals were completely changed. The problem facing the radiologist or the radiologic technologist as a result of these gross variations due to equipment malfunction is detecting the failure before clinically unacceptable films are produced. Christensen (7) states, "If one waits until the problems manifest themselves to a degree that the radiologists begin to reject radiographs, it is not only detrimental to one's reputation, but most often the problems compound themselves and become much more difficult to correct." This problem has also been explored by Poznonski and Smith (6) who have developed a means of detecting equipment malfunctions early. They state: "Fresh sensitometric strips have been used at Henry Ford Hospital for more than four years. By plotting the densities obtained for various

units, malfunctions of the processors (such as failure of recirculating pumps or dilution of developer) can be detected before they produce clinically significant disturbances in film quality." The data from the present study suggest that an alternative approach would be to simply process an unexposed film each day and chart the base-fog densities.

The relative speed and average gradient were not mentioned in the above discussion because the amount of change necessary to affect film diagnostic quality for these parameters was not known. However, the variations in relative speed and average gradient were less on a percentage basis than the variations in base-fog density.

6. CONCLUSIONS AND RECOMMENDATIONS

The results of this study show that there is a considerable amount of variation in the base-fog densities of films developed in several different automatic processors. It has also been shown that the base-fog densities of films developed in individual processors can vary considerably from day to day. Consequently, it should not be assumed that merely because these machines are automatic, they process films in an unvarying manner in a clinical environment. To provide radiographic images of consistent quality, it is recommended that in addition to performing routine maintenance tasks, periodic monitoring of system performance be undertaken.

REFERENCES

(1) JAMES, T. H., and C. E. K. MEES (Editors). The Theory of the Photographic Process. Third Edition. The Macmillan Co., New York (1966).

(2) EASTMAN KODAK COMPANY, Sensitometric Properties of X-ray Films (1963).

(3) AMERICAN STANDARDS ASSOCIATION PUBLICATION PH2.9 - 1964. Sensitometry of Medical X-ray Films (1964).

(4) BATES, L. M. A report on work carried out under contract number SAph-76496 between The Johns Hopkins University and the Bureau of Radiological Health, U. S. Public Health Service (May 1968).

(5) TER-POGOSSIAN, M. The Physical Aspects of Diagnostic Radiology, Harper and Row, New York (1967).

(6) POZNANSKI, A. K., and L. A. SMITH. Practical problems in processing control. Radiology 90:135-138 (January 1968).

(7) CHRISTENSEN, C. L. Using a photographic exposure meter as a densitometer. Radiologic Technology 41:131-138 (November 1969).

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(continued from inside of front cover)

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